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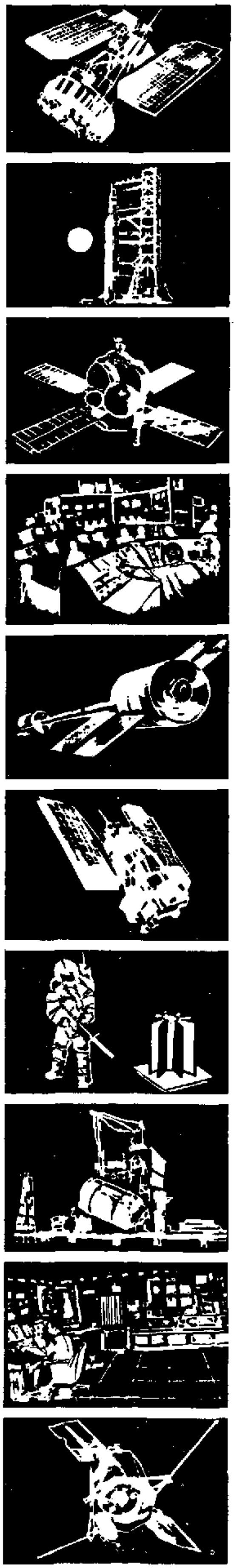

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STUDY FOR IDENTIFICATION OF BENEFICIAL USES OF SPACE

(PHASE II)

FINAL REPORT
VOLUME I
EXECUTIVE SUMMARY

CONTRACT NAS8-28179

NOVEMBER 1, 1973

SUBMITTED PER DPD #296, DR #MA-04

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Submitted Per DPD #296, DR #MA-04

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PREFACE

This Final Report on Phase II of the Study for Identification of Beneficial Uses of Space (B.U.S.) is comprised of two volumes:

Volume I – Executive Summary

Volume II – Technical Report

Volume II is further subdivided:

Book 1 – Sections I through IV, Introduction, Method of Study, Study Results, Conclusions and Recommendations

Book 2 – Section V, Appendices A through D

General Electric's Space Division, under contract from the NASA's Marshall Space Flight Center completed Phase I of the Study in December, 1972, and a Final Report for that phase was issued shortly thereafter.

In Phase II, conducted from December, 1972 to December, 1973, the Study has progressed to the investigation of the technology and programmatics involved in development of four of the products selected from those identified by User organizations who participated in Phase I. The selected Products/Organizations were:

- Surface Acoustic Wave Components – GE, Electronics Laboratory
- Transparent Oxides – Corning Glass Works
- High Purity Tungsten X-Ray Targets – GE, Medical Systems Business Division
- High Specificity Isoenzymes – Polysciences, Inc.

The methodology employed in this investigation and the results of that effort are reported herein.

The participating organizations supported General Electric's Space Division efforts by evaluating more than 30 major alternative candidate approaches for producing the above products, selecting specific processes for further study, and identifying requirements for nearly 70 experiment and test series necessary to the development of the selected processes.

Subsequent assembly of preliminary program timelines and milestones for such developments revealed a "comfortable" schedule of analyses, experiments and tests, design, development testing and fabrication of operational equipment; with reasonable tolerances in timing to allow for early redesigns, major retests, re-evaluation or results, and moderate redirection; and culminating in 1982-1983 operational dates.

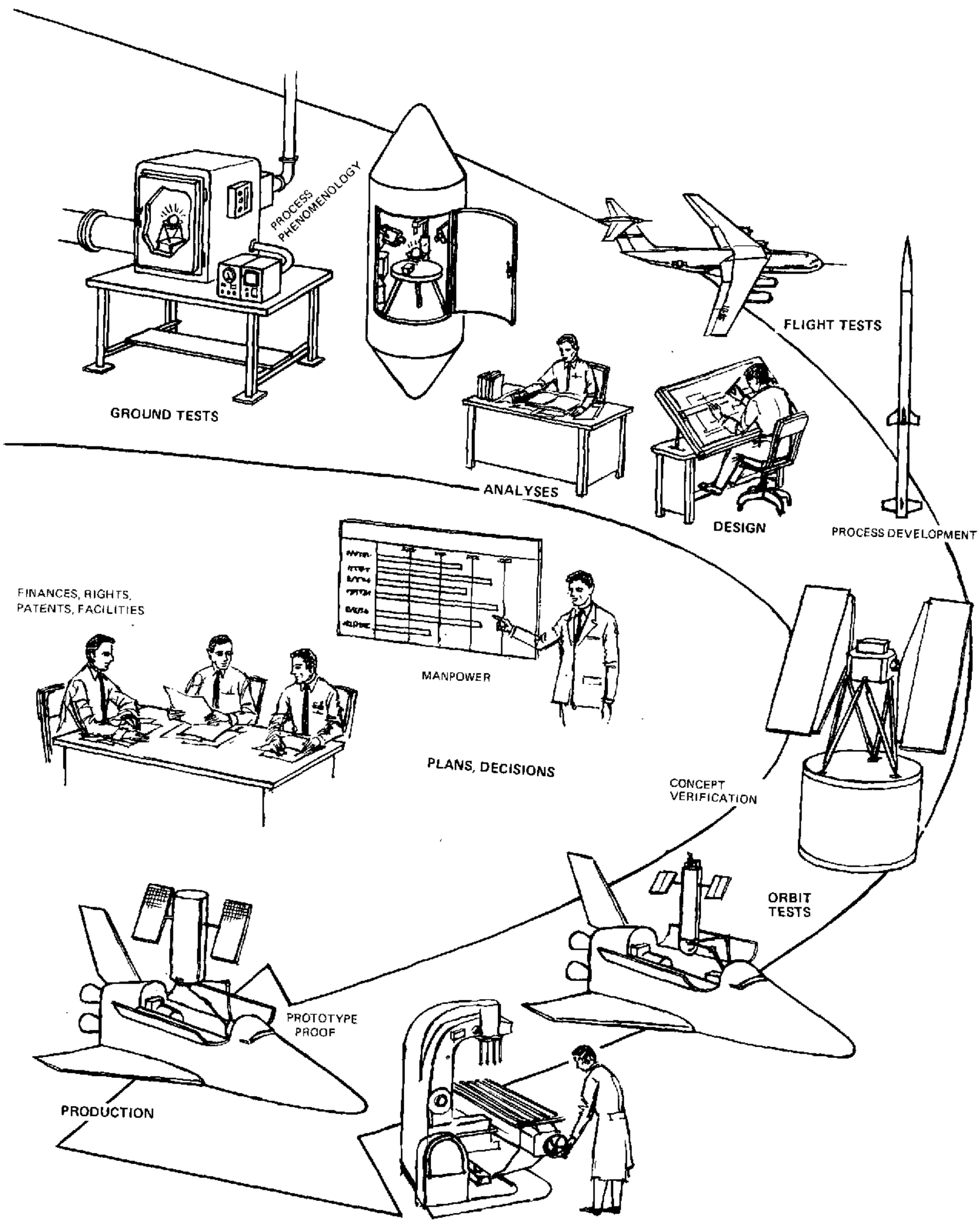
In addition to those Key Individuals from the participating User organizations who contributed specific product, process and planning data in each of their respective areas, the Study Manager acknowledges the considerable contributions of Mr. U. Alvarado and Mr. M. Clarke of the Study Team in analyzing and organizing the wealth of data accumulated; Mr. R. Spencer, the MSFC C.O.R. for the Study, in planning and directing the overall effort; and Mr. G. Wouch and Dr. D. Ulrich, of General Electric's Space Sciences Laboratory, in providing supporting space processing data.

As noted in the Phase I Final Report, publication of this Phase II report neither implies NASA endorsement of any specific product, process or experiment identified during this phase of the Study, nor a NASA commitment to pursue any program defined as part of this Study.

TABLE OF CONTENTS

Section		Page
I.	Introduction	1
II.	Study Objectives	4
III.	Relationship to Other NASA Efforts	5
IV.	Methods of Approach and Principal Assumptions	7
V.	Basic Data Generated and Significant Results	9
VI.	Study Limitations	13
VII.	Implications for Research	13
VIII.	Suggested Additional Effort	14

INDUSTRIAL SPACE PROCESSING EXPERIMENT REQUIREMENTS AND PLANNING DATA



I INTRODUCTION

By the mid 1980's, Space Shuttle-borne facilities are expected to enable the exploitation of space processing operations to provide a broad spectrum of products, Figure 1, for industrial Users on the ground.

PRODUCTS	BASIC SPACE PROCESSES REQUIRED
HIGH PURITY VACCINES	ELECTROPHORESIS
HIGH SPECIFICITY VIRAL INSECTICIDES	ELECTROPHORESIS (FREE FLOW)
* MULTI-GIGAHERTZ FREQUENCY SURFACE ACOUSTIC WAVE ELECTRONIC COMPONENTS	LARGE CRYSTAL GROWTH AND VIBRATION-FREE LITHOGRAPHY
SINGLE CRYSTAL AND/OR EUTECTIC HIGH TEMPERATURE TURBINE BUCKETS	LARGE CRYSTAL GROWTH AND/OR CONVECTIONLESS SOLIDIFICATION
* HIGH PURITY, DUCTILE TUNGSTEN X-RAY TARGETS	LEVITATION MELTING AND SUPERCOOLING
HIGH PURITY RADIOISOTOPES	PARTICLE MANIPULATION BY SMALL FORCES
LARGE, UNIFORM SILICON SINGLE CRYSTALS	LARGE CRYSTAL GROWTH AND/OR CONVECTIONLESS SOLIDIFICATION
UNIFORM GARNET SINGLE CRYSTAL FILMS	CONVECTIONLESS EPITAXIAL CRYSTAL GROWTH
* TRANSPARENT METAL OXIDES	LEVITATION MELTING AND UNIFORM SUPERCOOLING
* HIGH SPECIFICITY ISOENZYMES	ELECTROPHORESIS (LARGE PORE GEL) OR ISOELECTRIC FOCUSSING

*PRODUCTS INVESTIGATED IN THIS PHASE II STUDY

Figure 1. Typical Industrial Products Potentially Obtainable via Space Processing

Precursor development programs for such processes and products, however, may be expected to involve a sequence of analytical, experimental, design, fabrication and test steps in ground and flight facilities at earlier dates.

Such development programs, because of the required "mix" of space program characteristics with those of established ground-based industry, call for early planning and a careful melding of their individual operating methods, technologies and organizational roles.

This report presents the results of a Study on such planning and melding for four products (Figure 1) produced by specific selected processes which are expected to be included in the eventual spectrum of industrial space processes. For the selected processes, this report compiles the identified requirements and functions of developmental experiments and tests, the timing of necessary development program steps, and the anticipated decisions required during the development cycle.

I.1 PHASE II STUDY BACKGROUND

In Phase I[(1)] of the Study for Identification of Beneficial Uses of Space, the General Electric Space Division - led effort uncovered over 100 candidate Ideas for potential space-produced or -developed products, processes and services. Of these, 12 were shown to involve specific problems, issues, and needs, the resolution of which could conceivably be provided by required knowledge and capabilities obtainable in space facilities (Figure 2). Furthermore, specific User support and estimates of potential eventual benefits of these 12 Ideas were delineated.

	IDEA NO.		ISSUES, NEEDS, AND PROBLEM AREAS	REQUIRED KNOWLEDGE/CAPABILITIES
*	1	IMPRINTING CIRCUITRY ON CRYSTAL WAFERS FOR SURFACE ACOUSTIC WAVE ELECTRONICS	ELIMINATION OF VIBRATION FROM IMPRINTING SYSTEM	DECOUPLED PLATFORM FOR MOUNTING IMPRINTING SYSTEM (e.g., ELECTRON BEAM GUN) WHICH ELIMINATES LOW FREQUENCY VIBRATIONS, ACOUSTIC COUPLING.
	3	PARTICLE MANIPULATION BY SMALL FORCES	ELIMINATION OF GRAVITY MASKING EFFECT	FACILITY WHICH ELIMINATES OR COUNTERBALANCES GRAVITY FORCE SO AS TO ENABLE A VARIETY OF MICRO-FORCE INDUCERS (e.g., LIGHT, HEAT, SOUND, RF, ETC.) TO ACCELERATE PARTICLES IN VARIOUS MEDIA.
	5	VIBRATION TESTING OF SMALL MOTORS	IMPROVEMENT OF PRESENT 4 CPS LIMIT, ISOLATION FROM SONIC AND MAGNETIC FIELDS	DECOUPLED PLATFORM FOR MOUNTING PROTOTYPE MOTORS AND VIBRATION-MEASURING INSTRUMENTATION (e.g., LASER HOLOGRAPH) WHICH ELIMINATES SEISMIC VIBRATIONS AND ACOUSTIC COUPLING.
	6	SINGLE CRYSTAL AND EUTECTIC HIGH TEMPERATURE TURBINE BUCKETS	CERTAIN SUPERALLOYS NOT AMENABLE TO CASTING; PRESENT CRYSTALS SMALL AND CONTAIN DISLOCATIONS; EUTECTICS CONTAIN DISLOCATION, ETC.	FACILITY TO MELT SUPERALLOYS, REFRACTORY METALS, EUTECTICS WITHOUT CRUCIBLE; GROW LARGE CRYSTALS ALONG SPECIFIC PLANES, WITHOUT INTERNAL STRAINS, ANOMALIES CAUSED BY CONVECTION, PRODUCE EUTECTICS WITHOUT DEFORMATIONS CAUSED BY CONVECTION; PROVIDE SUPERCOOLING OF SIZEABLE SPECIMENS AFTER CRUCIBLESS MELT
*	30	HIGH PURITY TUNGSTEN X-RAY TARGETS	CONTAMINATION OF MELT BY CRUCIBLE	FACILITY TO MELT TUNGSTEN WITHOUT CRUCIBLE, PROVIDE SUPERCOOLING OF SIZEABLE AMOUNT AFTER CRUCIBLESS MELT
	42	PRECISE SEPARATION OF RADIOISOTOPES	HIGH SPECIFICITY SEPARATION TECHNIQUE	FACILITY WHICH ELIMINATES BUOYANCY, PRECIPITATION, CONVECTION FORCES; ALLOWS SMALL FORCES TO ACCELERATE ISOTOPE PARTICLES AT RATES RELATED TO SMALL DIFFERENCES BETWEEN ISOTOPES.
	46	SILICON CRYSTAL GROWTH	CONVECTION DURING CRYSTAL GROWTH	CRYSTAL-GROWING FACILITY WHICH DECREASES CONVECTIVE FORCES IN MELT TO MINIMIZE NON-UNIFORMITIES IN DOPANT DISTRIBUTION, THUS INCREASING UNIFORMITY OF CRYSTAL ELECTRICAL PROPERTIES; ALSO TO GROW LARGER CRYSTALS.
	59	EPITAXIAL GROWTH OF MAGNETIC BUBBLE MEMORY CRYSTALS	CONVECTION, LOSS OF SUPERSATURATION	EPITAXIAL CRYSTAL-GROWTH FACILITY TO ELIMINATE CONVECTIVE CURRENTS THAT CAUSE THE NON-UNIFORMITIES IN TEMPERATURE AND SATURATION LEADING TO NON-UNIFORMITIES IN FILM THICKNESS AND MAGNETIC PROPERTIES; ALSO TO GROW LARGER AREA CRYSTALS.
*	60	AMORPHOUS GLASSES AND REFRACTORIES	CRYSTALLIZATION DUE TO INCLUSIONS, CONVECTION	FACILITY TO MELT AND SUPERCOOL GLASSES AND CERTAIN OXIDES WITHOUT DEVITRIFICATION CAUSED BY CRUCIBLE SURFACES, CONVECTIVE CURRENTS, INCLUSIONS.
	84	BASIC HEAT TRANSFER DATA	CONVECTION DURING MEASUREMENTS	DATA ON THERMAL CONDUCTIVITY OF LIQUIDS (ESPECIALLY OILS) IN ABSENCE OF CONVECTION
*	89	SEPARATION OF ISOENZYMES	DENATURATION OF ISOENZYMES BY SEPARATION UNDER G LOADING	FACILITY TO SEPARATE ISOENZYMES WITH VERY WEAK FORCES SO AS TO AVOID DENATURATION WHICH OCCURS WHEN SEPARATION REQUIRES LARGER FORCES (e.g., WHEN PERFORMED IN ONE G)
	96	UTILIZATION OF BIORHYTHMS	TERRESTRIAL INFLUENCES	DATA ON PHYSICAL AND BEHAVIORAL WELL BEING OF SUBJECTS WHEN POTENTIAL INFLUENCES (e.g., LUNAR, MAGNETIC, GRAVITY, ETC.) ON BIORHYTHMS ARE VARIED. FOR USE IN POSSIBLE MODIFICATION OF DIAGNOSIS, THERAPY, WORK CYCLES.

*IDEAS INVESTIGATED IN THIS PHASE II STUDY

Figure 2. Required Knowledge/Capabilities

(1) , Study for Identification of Beneficial Uses of Space (Phase I), Final Report, GE Document #73SD4259, December 10, 1972 and April 23, 1973.

As a result of the Final Review of the Phase I Study, the NASA Advisory Group for the Study recommended that further steps be taken in advancing from the initial "identification" effort to the definition of technical and planning data which would be required for eventual implementation of selected Ideas. In addition, such steps were recommended for the purpose of maintaining non-aerospace Users' interest, and encouraging their involvement in the NASA applications effort.

In compliance with these recommendations and with direction of the NASA C.O.R., General Electric organized the Phase II Study to conform to the rationale summarized in Figure 3. As noted in that figure, much of the technique successfully applied in Phase I has been incorporated into Phase II:

- Emphasis on "specifics" (Ideas, requirements, Users)
- Utilization of Users as key information generators.

In addition, as in Phase I, the dialog method of eliciting User information, continued to play a vital role in Phase II.

1. PREPARATION FOR EVENTUAL IMPLEMENTATION OF SELECTED IDEAS BY:
   - EMPHASIS ON SPECIFIC IDEAS
   - DEFINITION OF SPECIFIC REQUIREMENTS

   AND

2. MAINTENANCE OF NON-AEROSPACE USERS INTEREST AND ENCOURAGEMENT OF THEIR PARTICIPATION IN NASA APPLICATIONS PROGRAM BY:
   - EMPHASIS ON SPECIFIC USERS
   - USER AID IN FURTHER DEFINITION.

TO RESULT IN

A. TECHNICAL DATA:
   - APPROACHES FOR IMPLEMENTATING SELECTED IDEAS
   - REQUIREMENTS FOR EXPERIMENTS TO VERIFY APPROACHES
   - MISSION PROFILES FOR SUCH EXPERIMENTS

   AND

B. PLANNING DATA:
   - TIMING AND EVENTS FOR R&D THROUGH OPERATIONAL IMPLEMENTATION
   - KEY MANAGEMENT CONSIDERATION RELATED TO SUCH TIMING AND EVENTS.

Figure 3. Phase II Study Rationale

1.2 STUDY RESULTS AND CONCLUSIONS

This phase of the Study has been successful in developing the data and maintaining the User rapport recommended by the NASA Advisory Group for the Study as interpreted in the Study rationale.

Technical Data. User response in generating alternative approaches for implementing their Ideas was enthusiastic and fruitful, as evidenced by the variety of alternative approaches they evaluated (see Figure 4). A total of about 30 major alternatives and over 100 lesser alternatives involved in a gamut from total processes to portions of process steps were considered for the four products under study.

STUDY ITEM	MAJOR ALTERNATIVE APPROACHES EVALUATED	OTHER ALTERNATIVES EVALUATED (NUMBER, TYPICAL EXAMPLES)
SEPARATION OF ISOENZYMES	SEPARATION VIA: • FREE ELECTROPHORESIS • SMALL PORE GEL ELECTROPHORESIS • LARGE PORE GEL ELECTROPHORESIS • ISOELECTRIC FOCUSSING • CHROMATOGRAPHY • OTHER SMALL FORCES	41 ALTERNATIVES INCLUDING: • PRESERVATION VIA: - FROZEN SOLUTION - LYOPHILIZATION - ADDITION OF ANTISEPTICS • PREPARATION OF GELS: - ON GROUND - IN ORBIT • LOADING OF SEPARATOR: - ON GROUND - IN ORBIT
TRANSPARENT OXIDE PROCESSING	HEATING AND MELTING VIA: • INDUCTION • LASER • ELECTRON BEAM • RF • SOLAR CONCENTRATOR	31 ALTERNATIVES INCLUDING: • LOADING OF MELTING SYSTEM: - ON GROUND - IN ORBIT - AUTOMATIC - MANUAL • POSITION CONTROL VIA: - ELECTROMAGNETICS - ACOUSTICS - RF - GAS JETS - ELECTROSTATICS
TUNGSTEN X-RAY TARGET PROCESSING	LEVITATION MELTING VERSUS FLOAT ZONE REFINING HEATING AND MELTING VIA: • RF • SOLAR CONCENTRATOR • ELECTRON BEAM	27 ALTERNATIVES INCLUDING: • HEATING PROFILE: - SLOW RISE - FAST RISE - DWELL BELOW MELT TEMPERATURE - NO DWELL BELOW MELT - SHORT DWELL DURING MELT - PROLONGED DWELL DURING MELT - NO DWELL DURING MELT • SHAPING VIA: - SPINNING DURING SOLIDIFICATION - GROUND BASED FORMING - MACHINING
FABRICATION OF SURFACE ACOUSTIC WAVE COMPONENTS	IMPRINTING OF CIRCUITRY VIA: • PROGRAMMED ELECTRON BEAM • X-RAY LITHOGRAPHY • PHOTOLITHOGRAPHY • LIFT-OFF PROCESSING CRYSTAL GROWTH VIA: • FLOAT ZONE • CZOCHRALSKI • FLUX • HIGH PRESSURE HYDROTHERMAL • VERNUIL • GROUND VERSUS IN ORBIT	12 ALTERNATIVES INCLUDING: • ULTRACLEANING VIA: - GROUND VERSUS IN ORBIT - BACK SPUTTERING - ION BEAM SCRUB • METALLIZATION VIA: - GROUND VERSUS IN ORBIT - SPUTTERING - VAPOR DEPOSITION • CRYSTAL ACOUSTIC SURFACE: - AS GROWN - CUT AND POLISHED

Figure 4. Summary of Alternate Processing Approaches

Engineering and scientific judgements, utilizing and extrapolating ground-based data and limited data from space experiments, were employed in comparing the applicable alternatives against a set of criteria (Figure 5) in order to select the "best" approach for each product.

For each selected approach, further analyses were carried out to determine where experiments and tests would be required for attaining a sufficient state-of-the-art to carry each approach to the point of commercial production. Typically, experiments and tests were required for obtaining data on phenomenology of specific materials under various conditions considered for space processing, for establishing processing parameters, for resolving otherwise unresolvable alternatives, for verifying processing concepts, etc.

EASE OF PROCESSING

ALLOWABLE TOLERANCES IN ENVIRONMENT CONDITIONS
REQUIRED PRECISION OF PERFORMANCE
DURATION OF PERFORMANCE
COMPLEXITY OF FUNCTIONS

EQUIPMENT REQUIREMENTS

DEGREE OF AUTOMATION FEASIBLE
RELATIVE SIZE, WEIGHT

SUPPORT UTILITIES, SERVICES

VARIETY OF TYPES
RELATIVE AMOUNT

MATERIALS

RELATIVE AMOUNTS OF RAW MATERIALS
RELATIVE AMOUNTS OF WASTES

TIMELINESS

RELATIONSHIP OF AVAILABILITY TO NEED

FINAL PRODUCT

QUALITY
RELATIVE COSTS

VERSATILITY

POTENTIAL FOR OTHER APPLICATIONS

Figure 5. Criteria for Selection Among Alternative Approaches

Based on the requirements so derived, test facilities were identified for carrying out the tests. In cognizance of the economy that must pervade commercial ventures, the concept of "low cost testing" was imposed here. Briefly, this concept asks, in reviewing requirements for test facilities, "Are there ground-based, or other low cost facilities, possibly not commonly utilized by commercial organizations, in which partial or complete experiments and tests or process steps could be carried out, in order to minimize space testing, and, thus minimize program costs?" In conformance with this concept, more than two-thirds of the experiments and tests identified in the Study are oriented toward low cost facilities. A summary of the number of experiments and tests in the various facilities is given in Figure 6.

FACILITY	NUMBER OF TEST SERIES*
GROUND LABORATORIES	22
CENTRIFUGE	2
ENGINEERING TEST LABORATORIES	5
DROP TOWER	3
KC-135 (KEPLERIAN TRAJECTORIES)	8
SOUNDING ROCKETS	7
SPACECRAFT	8
SHUTTLE SORTIE LAB	11
TOTAL	66

*EACH SERIES CONSISTS OF 1 TO 120 RELATED RUNS

Figure 6. Facilities Required for Experiments and Tests

Planning Data. A primary basis for any continued effort on the products under study will be the timelines and milestones generated during this Study. The experiments and tests derived earlier were ordered into logical sequences, supplemented by estimates of required precursor analytical studies and experiment development efforts. In addition, engineering, design, manufacturing and hardware development schedules preparatory to prototype production proof-testing were assembled, as were program steps for providing support equipment and ground facilities. The timeline and milestones for each product were then completed by listing key organization events. A review of the four timeline/milestones reveals several major points listed in Figure 7.

PROGRAM EFFORT	KEY TIMING
ANALYTICAL INVESTIGATIONS	INITIATION IN 1973, EARLY 1974
GROUND LABORATORY EXPERIMENTS AND TESTS	INITIATION LATE 1973, EARLY 1974
DROP TOWER EXPERIMENTS AND TESTS	MID 1974 TO MID 1975
ZERO G AIRCRAFT EXPERIMENTS AND TESTS	MID 1975 THROUGH 1977
SOUNDING ROCKET EXPERIMENTS AND TESTS	1975 THROUGH 1979
AUTOMATED SPACECRAFT EXPERIMENTS AND TESTS	1975 THROUGH 1979
SHUTTLE EXPERIMENTS AND TESTS	LATE 1979 THROUGH 1983
PROTOTYPE PROOF TESTS	LATE 1981 THROUGH LATE 1982
FORMATION OF CORPORATE TEAMS	1977 THROUGH 1979 (FINAL)
LEGAL/FINANCIAL ARRANGEMENTS	1973, 1974 (INITIAL) 1975 THROUGH 1980 (FINAL)

Figure 7. Summary of Key Timeline/Milestone Information

As a result of the completed timelines/milestones, it was possible to construct the flow of decisions required to implement production of each of the products. Such decision flows were assembled, and supported by documented rationale as to the alternatives available for decision as well as the estimated probabilities associated with each alternative.

Conclusions. The study has essentially met all the guidelines and objectives laid out for this phase of effort, and the results enable the following general conclusions:

1. The study results, reflecting User inputs to each task, verify that we have maintained the previously initiated two-way communications between the aerospace community (represented by NASA and General Electric's Space Division) and non-aerospace industry (represented by Polysciences, Inc., Corning Glass, and General Electric's Electronics Lab and Medical Systems Business Division). As an added facet, we have, as by-products of the Phase I effort, also opened new communications through identifying Users with several new ideas for space processing. Typical examples are beryllium composites for aircraft structural and engine components as well as for nuclear reactor reflectors, and tungsten carbide valve components for the oil industry.

2. Within the limits of available information and good engineering and scientific judgement, there are justifiable logical implementation approaches requiring certain specific space processing steps for the four products on which this phase of study is based.

3. The limited available applicable data, variations in predicting 1980's state-of-the-art, and depth of analysis compatible with the level of the study, has led to a necessarily broad scope of requirements for experiments and tests to solve the unknowns and verify the judgements involved in those selections.

4. Preliminary schedules of desirable programs to implement the development of the selected approaches to the point of production appear "comfortable" with sufficient flexibility to accommodate moderate levels of redirection or re-study where programmatic or technical inhibitions occur.

5. While technical decisions frequently appear as major "nodes" in the flow of decisions involved in implementation of each of the subject selected approaches, in a carryover from the Phase I study, legal and financial decisions continue to be of concern to Users.

II STUDY OBJECTIVES

The Phase II Study has been directed toward carrying out the following objectives:

1. Selection of the best approach for implementing each of the selected ideas from the Identification of Beneficial Uses of Space Study (Phase I).

2. Definition of requirements for experiments to verify selected approaches, including mission profiles, and generic definition of suitable vehicles or appropriate ground facilities.

3. Establishment of technical timelines and milestones to achieve operation (production or service, as appropriate) of prototype facility/pilot plant for each selected idea.

4. Formulation of planning profiles to relate key management data to timelines and events. Data to include, at least, development steps, decision points, alternatives, risks, major facilities and unique manpower.

II.1 SELECTION OF BEST APPROACH

This objective was intended to provide a data base and rationale for those processes or portions of processes which would require, or which would be improved by, performance in the orbital environment. The implication was that consideration was to be given to various ground- and space-based alternatives for each process step and sequence of steps, and that unambiguous information could be developed against a set of criteria established to define "best" approach. While most of the 130 defined major and minor alternatives for the processing of the four selected products were readily resolved, evaluation against the criteria was heavily judgemental, and available information could not enable the clear resolution of some 10 percent of the alternatives. These unresolved issues were subsequently subjects for required experiments and tests. Typically, selections could not be justified for ground-based versus orbit-based preparation of gels for isoenzymes separation, ground-based versus orbit-based shaping of the tungsten material, heating rate for the transparent oxides, etc.

II.2 DEFINITION OF REQUIREMENTS FOR EXPERIMENTS

Even where judgement could logically support the selection of one alternative over others, it was understood that present state-of-the-art in many phenomenological and process areas would be insufficient to proceed very far with implementation of most approaches. This objective, thus, required examination of elements in the selected approaches against available state-of-the-art, and definition of requirements for experiments/tests where such insufficiencies were observed. More than 90 of such state-of-the-art "gaps", such as heating and convection in large pore gels during long duration electrophoresis at voltage gradient < 10 volts/cm, effects of containerless supercooling on tungsten, etc., were uncovered in the dialogs between the Study Team and the four User organizations. The dialogs carried on to meet this objective were particularly valuable in cross-educating the participants.

II.3 ESTABLISHMENT OF TIMELINES AND MILESTONES

Accomplishment of the proceeding objectives provides an extensive technical requirements data base, for which this objective was intended to provide a supporting initial technical planning data base.

With a 1982 shuttle flight as a given baseline for the full-scale production of the selected products, preliminary scheduling of the precursor research and development effort for all four products indicates sufficient time for series sequencing of key program elements. The consequent ability to acquire, analyze, and absorb data from a precursor experiment or analysis before initiating a subsequent effort will be beneficial to all concerned. All participants felt comfortable with the resulting schedules and with the flexibility inherent in the series arrangement of key program elements.

II.4 FORMULATION OF PLANNING PROFILES

A reality of implementing the programs which meet the preceding objective is that many administrative decisions are required prior to, and during, the programs. This objective is aimed at illustrating the content of such decisions, their interrelationships and relationships with technical decisions. The participating Users were requested to impose business planning groundrules typical of their own organizations in assembling such decisions, assessing the risks, and indicating their preferred alternatives. Examples of such decisions are given in Figure 8.

DECISION TO BE MADE	DATE	ALTERNATIVE	PROBABILITIES	USER PREFERRED ALTERNATIVE
COMMITMENT OF LIMITED USER FUNDS TO SUPPORT NASA-FUNDED TESTS ON LEVITATION MELTING OF TUNGSTEN	1973	A. COMMIT B. DO NOT COMMIT	1.00 0	X
EVALUATION OF POTENTIAL MARKET FOR TRANSPARENT OXIDES	1977	A. FAVORABLE B. UNFAVORABLE	0.80 0.20	X
FORMATION OF PRODUCTION ORGANIZATION FOR SURFACE ACOUSTIC WAVE COMPONENTS	1979	A. GE B. OTHER USER C. NOT FORMED	0.50 0.50 0	X
ADDITION OF NEW LAB SPACE FOR SEPARATION OF ISOENZYMES	1975	A. ADAPT EXISTING B. BUILD NEW, SEPARATE C. ADDITION TO PRESENT	0.20 0.10 0.70	X

Figure 8. Typical Management Decisions Formulated During Study

III RELATIONSHIP TO OTHER NASA EFFORTS

In the past year, there has been a marked increase in the number and applicability of plans and programs related to subjects of this study. Thus, in addition to those useful past and continuing plans and programs discussed in the Phase I Final Report, we have listed in Figure 9 several typical examples which have been useful during Phase II.

The potential continuity of programs beyond the conceptual phases of this Study, as exemplified by some of the listed programs, aided materially in maintaining the interest of the non-aerospace participants in the Study. Without such possibilities, the nearly 10 year hiatus until Shuttle operations would have had a debilitating effect on that interest.

III.1 FUTURE SPACE PROGRAM PLANS

The available traffic model proved useful in framing realistic timelines for implementing the four Ideas in the Study. An example is the approved flights of automated spacecraft with astronomy missions in 1976 and 1978 which might "piggy-back" limited experiment instrumentation to measure low frequency vibrations in support of surface acoustic wave component development.

With sufficient planning, the results of B.U.S.-related investigations could undoubtedly be incorporated in experiments planned for scientific disciplines and technologies. Therefore, it will be advantageous to plan scientific and technology experiments taking into consideration the needs in application areas that are the subject of the study. For instance, investigations on particulate concentrations about a spacecraft and possible countermeasures to eliminate optics contamination on astronomy or earth survey sensors will be important in designing the systems for B.U.S.-related applications requiring contamination-free environments.

III.2 SPACE SHUTTLE

Based on the planned frequency, reusability, and economy of shuttle transportation, the Users involved in the Study have begun to accept the reality and businesslike aspects of shuttle operations. Shuttle program literature indicates that space processing can be carried on under conditions conducive to "good business", on time delivery, regular operations, cost effective performance.

III.3 ELECTROPHORETIC SEPARATION

Electrophoretic processing in the space environment has generated wide interest among potential Users as a powerful concept for the production of ultrapure biological materials. Studies of the free flow method have been reviewed in performing the evaluations in this Study.

TITLE	SPONSORING CENTER	PERFORMING ORGANIZATION	CONTRACT NO(S).	PERIOD OF PERFORMANCE	OBJECTIVES	PRESENT STATUS	KEY RESULTS
1. FUTURE SPACE PROGRAM PLANS	HEADQUARTERS	ALL CENTERS	MANY	CONTINUING	INTEGRATED PROGRAM OF SCIENTIFIC, TECHNOLOGICAL, AND APPLICATION EXPERIMENTS, TESTS, OPERATION.	FIRM PLANS, FOR DEDICATED AUTOMATED SPACECRAFT, SKYLAB, ASTP, SHUTTLE ENGINEERING.	1973 NASA PAYLOAD MODEL. AVAILABILITY OF ACCOMMODATIONS FOR OTHER PAYLOADS NOT DEFINED.
2. SPACE SHUTTLE	JSC	NORTH AMERICAN ROCKWELL	NAS9-1400	8/72 - CONTINUING	DEVELOP THE SPACE SHUTTLE.	IN EARLY PHASE C.	SPACE SHUTTLE SYSTEM PAYLOAD ACCOMMODATIONS JSC 07700, VOL. 14, REV. A, JULY 16, 1973.
3. ELECTROPHORETIC SEPARATION	MSFC	GE	NAS8-24793 NAS8-27797	8/69 - 10/72	EXPERIMENTS ON APOLLO 14 AND 16 TO DEMONSTRATE FREE FLOW ELECTROPHORETIC SEPARATION.	EXPERIMENTS PERFORMED. LIMITED SUCCESS.	FREE FLOW ELECTROPHORETIC SEPARATION IN SPACE APPEARS FEASIBLE.
			NAS8-28365		SKYLAB DEMONSTRATION REPORT ISSUED.	GROUND-BASED R&D COMPLETE.	
4. ECONOMIC ANALYSIS OF CRYSTAL GROWTH IN SPACE	MSFC	GE	NAS8-27942	9/71 - 7/72	ASSESS ELECTRONIC SINGLE CRYSTAL PRODUCTION AND PROJECT FUTURE REQUIREMENT, REVENUES, COSTS, PROFITS. COMPARE SPACE PRODUCTION VERSUS TERRESTRIAL.	ANALYSIS COMPLETE, FINAL REPORT ISSUED.	SOPHISTICATED COMPOUND SINGLE CRYSTALS APPEAR JUSTIFIED FOR SPACE PRODUCTION.
5. LEVITATION MELTING FACILITY	MSFC	GE	NAS8-24683 NAS8-26157	6/69 - 10/72	DEVELOP FACILITY FOR CRUCIBLESS MELTING AND SOLIDIFICATION. PRIMARILY FOR METALLURGICAL RESEARCH AND DEVELOPMENT.	COMPLETED. ACHIEVED OBJECTIVES.	MOST PROMISING EXPERIMENTAL AREA IDENTIFIED. APPROACHES EVALUATED. DESIGN CONCEPT ESTABLISHED.
			NAS8-27228		PROTOTYPE DEVELOPMENT.	EQUIPMENT READY FOR DEMONSTRATION.	GROUND DEMONSTRATION OF POSITIONING CONTROL. MATERIALS WITH NEW PROPERTIES FOUND LIKELY.
6. MATERIALS PROCESSING	HEADQUARTERS	NATIONAL BUREAU OF STANDARDS	NOT APPLICABLE	1972-1973	EXAMINE GROWTH AND PERFECTION OF CRYSTALS. ESTIMATE EFFECTS OF CONVECTION ON GROWTH.	IN PROCESS.	DEFINITION OF KEY UNKNOWNS IN GRAVITY - FREE GROWTH OF CRYSTALS.
7. SPACE PROCESSING	MSFC	MSFC	NOT APPLICABLE	1966 - CONTINUING	DEVELOP, AND SPONSOR DEVELOPMENT OF, TECHNIQUES FOR DEVELOPING OR PRODUCING PRODUCTS, PROCESSES IN SPACE.	IN PROCESS.	PATENTS, ANALYTICAL DATA, GROUND EXPERIMENTS, DROP TOWER TESTS, AEROBEE EXPERIMENTS, ETC. ON ZERO "G" PROCESSES.
8. SPACE SHUTTLE TRAFFIC MODEL	NASA HEADQUARTERS	NASA-MSFC	NOT APPLICABLE	CONTINUING	PLANNING PURPOSES. GUIDE DEVELOPMENT OF SHUTTLE, TUG, SORTIE LAB.	1973 MODEL ISSUED.	NASA TMX 64751 TRAFFIC MODEL FOR 1980 - 1990.
9. SORTIE LAB (AND PALLET)	ESRO	MBB OR ERNO CONSORTIUM	NOT APPLICABLE	7/73 - CONTINUING	PROVIDE EXPERIMENT PAYLOAD ACCOMMODATIONS FOR SHORT DURATION FLIGHTS.	EUROPEAN COMMUNITY COMPETITION TO DECIDE BUILDER.	NASA-ISSUED SORTIE LAB USERS GUIDE, APRIL 1973; PRELIMINARY DATA ON DESIGN, OPERATIONS.
10. CRYSTAL GROWTH IN FUSED SOLVENTS	MSFC	GE	NAS8-28114	12/71 - CONTINUING	IDENTIFY USE FOR MATERIALS AND DEVELOP METHOD.	SPACE EXPERIMENT IN DESIGN.	SEVERAL MATERIALS IDENTIFIED, CRYSTALS GROWN, GRAVITY-RELATED DEFECTS IDENTIFIED.
11. REQUIREMENTS AND CONCEPTS FOR MATERIALS SCIENCE AND MANUFACTURING IN SPACE PAYLOAD EQUIPMENT STUDY	MSFC	TRW	NAS8-28938	CONTINUING	REQUIREMENTS DEFINITION, EQUIPMENT IDENTIFICATION, PAYLOAD DESIGN CONCEPTS, OPERATIONAL ANALYSIS, PROGRAMMATICS.	REPORT ISSUED - STUDY CONTINUING.	COMMERCIAL EQUIPMENT IDENTIFIED, MODULAR CONCEPTS DEFINED, PAYLOAD CONFIGURATIONS DEFINED.
12. PHASE B STUDY OF FREE SUSPENSION SYSTEM FOR SPACE MANUFACTURING	MSFC	GE	NAS8-29680	CONTINUING	SELECTION OF APPROACH FOR ELECTROMAGNETIC SUSPENSION SYSTEM FOR CONTAINERLESS PROCESSING OF MATERIALS.	ANALYSES, TRADE-OFFS, TESTS IN PROCESS.	OVER 200 POTENTIAL MATERIALS IDENTIFIED, 8 COIL SYSTEMS EVALUATED.
13. LOW COST TESTING	NASA	MANY	MANY	CONTINUING	SHORT DURATION EXPERIMENTS IN, OR SIMULATING, SPACE ENVIRONMENT.	DROP TOWERS - IN USE. ZERO "G" AIRCRAFT - DECISIONS PENDING. SOUNDING ROCKET - GROWING USE. PIGGYBACK ON BOOSTERS, SPACECRAFT - NOT FREQUENT. LDEF - IN PLANNING.	CONSIDERABLE VALUABLE DATA OBTAINED IN PAST ON MATERIAL BEHAVIOR, EQUIPMENT PERFORMANCE IN ZERO "G".

Figure 9. Other NASA Plans and Programs Related to this Study

III.4 ECONOMIC ANALYSIS OF CRYSTAL GROWTH IN SPACE

The crystals required for implementation of surface acoustic wave components have been addressed here, and pertinent information utilized, as required, to evaluate substrate materials and required perfection of crystals for the approaches in this Study.

III.5 LEVITATION MELTING FACILITY

The three listed contracts have contributed to two of the products in this Study, the production of high purity tungsten x-ray targets, and the production of transparent oxides.

III.6 MATERIALS PROCESSING - NATIONAL BUREAU OF STANDARDS (NBS)

We have maintained a continuing survey of NBS results which have proved useful in providing the B.U.S. Study with a preliminary insight into the current unknowns concerning the possible effects of a gravity free environment on crystal growth.

III.7 SPACE PROCESSING AT MSFC

Past and current MSFC information relating to crystal growth, high purity refractories, and high specificity biologicals have provided a wealth of background for definition of alternative approaches to implementing the four Ideas Under Study.

III.8 SPACE SHUTTLE TRAFFIC MODEL

Although the timelines constructed for this Study were not constrained by the published traffic model, it was deemed reasonable to review the model for any major discrepancies between it and the desired Shuttle support called for in the timelines. No major discrepancies were found, although some 1979 verification tests of this Study do not fit the scheduled Sortie Mission Plan for space processing. Such tests, however, would be relatively simple, and could likely be automated for accommodation in one or two of the 19 flights of automated payloads.

III.9 SORTIE LAB AND PALLET

Lack of definition of the European Spacelab was overcome through use of the NASA Users Guide, which provided sufficient, typical data to enable participants in this Study to develop conceptual definitions for implementing their alternative approaches.

III.10 CRYSTAL GROWTH IN FUSED SOLVENTS

Continuing interfaces between personnel involved in the Crystal Growth Study and B.U.S. participants supporting Surface Acoustic Wave Component fabrication, have been beneficial to this Study, and should continue to be mutually supportive.

III.11 REQUIREMENTS AND CONCEPTS FOR MATERIALS SCIENCE AND MANUFACTURING IN SPACE

While there are processes and process steps defined in the B.U.S. Study that are not addressed in the referenced program, the available information has been highly useful to the B.U.S. participants in developing the required testing to support implementation of their concepts.

III.12 PHASE B STUDY OF FREE SUSPENSION SYSTEM

One of the latest applicable programs, this reference has provided considerable insight into problems and their possible solutions for the B.U.S. Study areas of Transparent Oxide Processing and Tungsten X-ray Target Processing.

III.13 LOW COST TESTING

Data was assembled for acquainting the B.U.S. participants with unique test facilities which offer conditions related to various space flight environments, but which may be operated for relatively low cost. The low cost feature, and the fact that there were useful development steps that could be accomplished prior to the 1979-1980 Shuttle, emphasized the reality of the on-going Space Processing program.

IV METHODS OF APPROACH AND PRINCIPAL ASSUMPTIONS

IV.1 ASSUMPTIONS AND GUIDELINES

Assumptions and Guidelines for the Phase II Study were included in the Statement of Work issued November 17, 1972. All such Assumptions and Guidelines were accepted and followed throughout the Study. A review of these Guidelines and Assumptions follows:

Guideline III.A. "As initial direction, the contractor shall utilize the methodology developed in the Identification of Beneficial Uses of Space Study to continue this effort."

As in Phase I, dialogs with the participating Users, supplemented by analysis carried out by both Users and consultants, were the major source of information for the Study. Mutually supporting analyses by the Space Division Study Team and the participating Users followed the pattern established in Phase I, and produced the results reported herein.

Guideline III.B. "Only Ideas identified in the Identification of Beneficial Uses of Space Study which have favorable application prognosis will be used."

The four Ideas carried through Phase II: Separation of Isoenzymes, Transparent Oxide Processing, Tungsten X-ray Target Processing, and Surface Acoustic Wave Component Fabrication, all are products of the named Study.

Guidelines III.C. "It is implicit that production or operation will be carried out through the use of the Space Shuttle. The Sortie Lab will be the facility for manned and unmanned operations of less than seven days duration. Deployable/retrievable modules will be used for unmanned operations of more than seven days. There will be no orbiting facility for manned operations longer than seven days."

While the production phase for two of the products under study (Tungsten X-ray Targets, Transparent Oxides) would benefit economically from longer duration manned flights, even the shorter cycle is felt to be economically feasible. In all cases, a high probability exists that the defined process could be automated for unmanned operations of longer durations.

Guideline III.D. "Planning data shall be based on a 1982 shuttle flight."

In conjunction with the C.O.R., it was agreed that this Guideline should be interpreted as referring to the earliest date of full scale production, and the Shuttle experiments, verification tests, and proof testing could be considered for earlier flights.

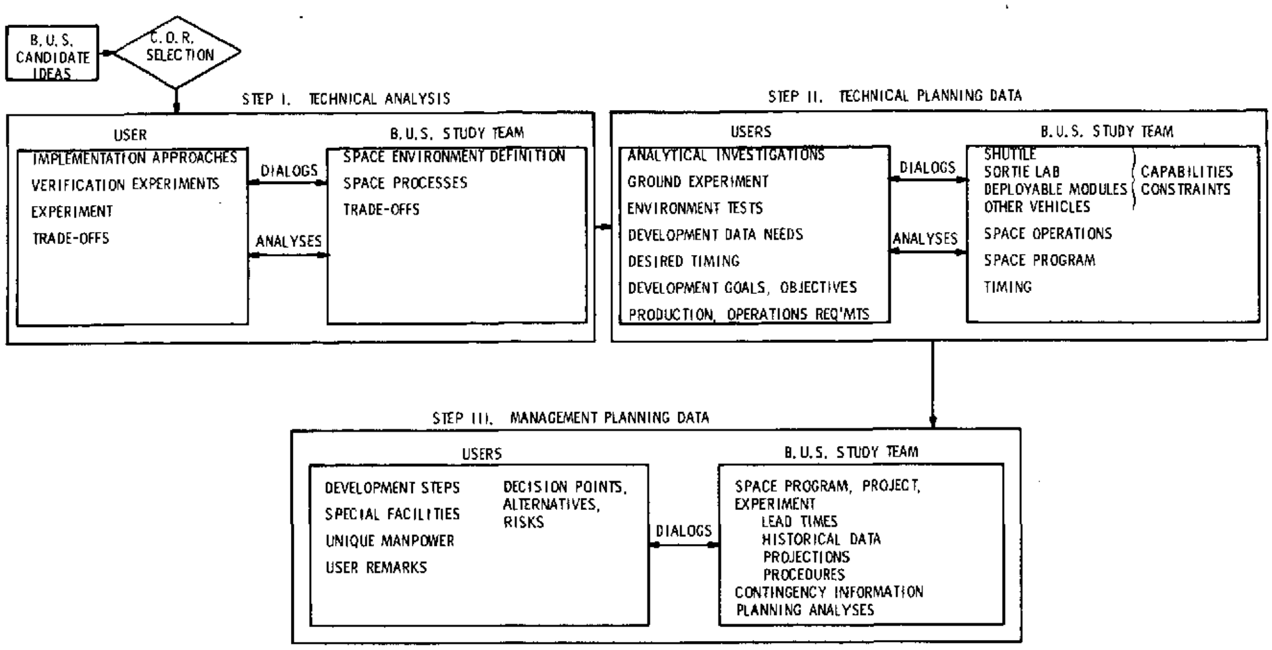


Figure 10. Study Logic

IV.2 STUDY APPROACH

The objectives discussed in Section II have been accomplished through the three-step process pictured in Figure 10.

After the NASA C.O.R. indicated his preferred priorities of the candidate Ideas identified in the Phase I Study, we initiated the solicitation of participating Users to assess their interest in continuing into the Phase II Study. A measure of commercial industry interest in space processing may be inferred from the fact that the organizations associated with the four Ideas at the top of the priority list agreed, with no hesitancy, to continue the Study.

Utilizing the User/Study Team dialog methodology, successfully developed in Phase I, we proceeded on the steps shown in the diagram. As shown in each step, both parties - Study Team and User Organizations have had specific responsibilities, and the blending of that effort, through dialogs and analyses, have produced the desired results.

IV.3 TASKS SUMMARY

While the Study Logic provided the overall strategy of the Phase II Study, it was the implementation of specific Study Tasks that defined the work that was accomplished. Figure 11 depicts a brief version of those tasks.

Task 1 reviewed the various means by which each idea could likely be implemented. These various approaches were then compared on the basis of technical and business criteria designed to filter out the less favorable, and each of those surviving was defined to a level which enabled understanding of its governing technology.

FOR EACH OF THE FOUR SELECTED IDEAS:

TASK 1.0 DEFINITION OF BEST IMPLEMENTATION APPROACH
- 1.1 DEFINITION OF CANDIDATE APPROACHES
- 1.2 SELECTION OF BEST APPROACH
- 1.3 DEFINITION OF BEST APPROACH

TASK 2.0 DEFINITION OF REQUIREMENTS OF EXPERIMENTS TO VERIFY SELECTED APPROACH
- 2.1 IDENTIFICATION OF CRITICAL ELEMENTS IN SELECTED APPROACH
- 2.2 ANALYSIS OF CRITICAL ELEMENTS
- 2.3 DEFINITION OF EXPERIMENT REQUIREMENTS

TASK 3.0 DESIGN OF MISSION PROFILES FOR EXPERIMENTS

TASK 4.0 ESTABLISHMENT OF TIMELINES AND MILESTONES
- 4.1 REQUIRED RESEARCH AND DEVELOPMENT PROGRAMS
- 4.2 TIMELINES AND MILESTONES

TASK 5.0 FORMULATION OF PLANNING PROFILE
- 5.1 IDENTIFICATION OF DECISIONS
- 5.2 DEVELOPMENT OF DECISION TREE
- 5.3 OTHER CONSIDERATIONS

Figure 11. Phase II Study Tasks

Task 2 investigated each pertinent technology to uncover its elements without which successful accomplishment could not be expected. Comparison of those elements against state-of-the-art then highlighted gaps in the state-of-the-art that must be filled in order to carry out the selected approach. It is these "gap-fillers" that give rise to the requirements for experiments. Such experiments have been defined so as to provide sufficient state-of-the-art in specific areas to enable accomplishment of each derived approach.

For each of the defined experiments, Task 3 was charged with constructing its mission profile in sufficient detail to identify key timing, operations, support, etc.

Task 4 supplied Technical Planning data to complement the requirements data, and serve as a basis for subsequent management planning data. Each derived approach was analyzed to determine a preliminary sequence of development steps required to bring the approach to fruition, and the duration of these steps. Assembly of these steps and their durations into a continuous timeline, and annotation of key events on that timeline completed this task.

Task 5 provides a preliminary insight into the major managerial data involved in implementing the derived development programs. Technical decisions were identified from the preceding data, supported by estimates of success probabilities of alternative activities. A single, time-phased plot of such information has been provided for each Idea under study, as well as key related considerations such as facilities and organization.

V BASIC DATA GENERATED AND SIGNIFICANT RESULTS

The enthusiastic support of the participating User organizations was instrumental in generating the quantity and quality of relevant material necessary for this phase of the Study.

It was first, important to give consideration to a sufficient number of technically possible alternative approaches for implementing each Idea selected for study to avoid the possibility that a potentially useful approach would be overlooked. Figure 4 reflects the breadth of that effort.

Beyond that step of the Study, it was important to recognize, and estimate advances in, the state-of-the-art in dozens of disciplines and technologies in order that key experiments and tests required for development of selected approaches not be overlooked. The results summarized in Figure 6 are a measure of the scope of that task.

Subsequently the Study demanded the organization of a logical sequence of such experiments and tests fitted into a consistent program of scientific, engineering, manufacturing, and administrative functions, and overlaid with the permutations and combinations offered by the possibilities of space and/or ground activities. Figure 7 briefly summarizes the dozens of milestones representative of that work.

Finally, it was necessary to extract from the over one hundred program timelines and milestones, the key decisions implicit in carrying out such programs, documenting the multiplicity of alternatives available to the decision makers, and estimating the probabilities associated with those decisions. Figure 8 provides a small sample of the results of this effort.

In all, the number and variety of items addressed in this Study exercised the Space Division/User participants mutually supportive Study Approach to the fullest extent in generating the data summarized below.

V.1 DEFINITION OF IMPLEMENTATION APPROACH

The User participants first defined the generic process(es) which their experience indicated could likely provide the desired products. Simplified examples of such processes for Tungsten X-ray Targets are given in Figure 12. At this level, a few alternatives were identified.

Such alternatives, and the many others that developed from expansion of the initial generic processes and dialogs between Space Division Study Team members and the User participants, were documented as candidate approaches for subsequent evaluation. Figure 13 provides an example of some typical alternative approaches considered for the processing of Tungsten. Considerably more detailed definition of all alternative approaches is given in Volume II of this report. It should be noted, that, in all appropriate cases, the alternatives of ground versus Space Processing, were reviewed for each candidate approach.

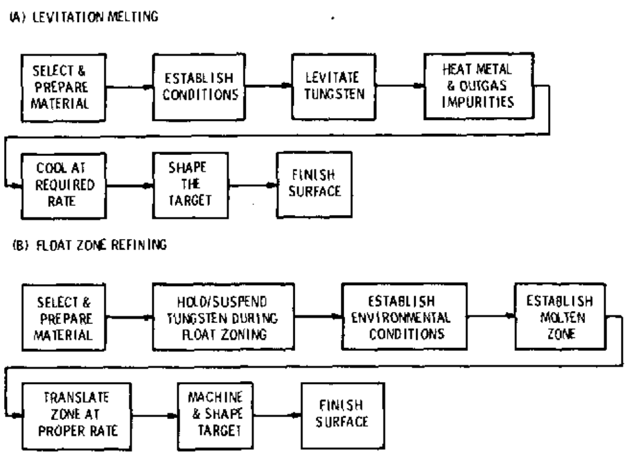


Figure 12. Candidate High Purity Tungsten X-ray Target Processes

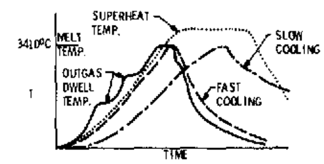
PARAMETER	ALTERNATIVES
QUALITY OF MATERIAL TO BE USED	LOW PURITY, HIGH INTERSTITIALS VS. 0.9999 PURITY ROD
SIZE OF EACH TUNGSTEN SPECIMEN	ENOUGH FOR SOLID TARGET VS. MATERIAL FOR RING
METHOD OF HEATING	RF ENERGY VS. SOLAR POWER VS. ELECTRON STREAM
TEMPERATURE PROFILE	
GASEOUS ENVIRONMENT	HIGH VACUUM VS. INERT GAS
SHAPING OF THE TARGET	COLD WORKING VS. HOT WORKING VS. MACHINING VS. SPINNING

Figure 13. Typical Alternatives in Tungsten X-ray Target Processing

All of the alternate approaches were then subjected to collective scrutiny and evaluation by the Study Team and appropriate Users, with frequent consultation by key experts. Where necessary, those experts have supplied reports, which appear as Appendices in Book 2 of Volume II of this Final Report. As a result of the evaluation, which was based heavily on the scientific and engineering judgement of the evaluators, selections were made in most of the processing areas. A brief summary of the selected approaches, and those areas for which there was insufficient information to justify a rational selection, is given in Figure 14. Volume II contains an in-depth discussion of the evaluation of the candidate approaches.

IDEA	PROCESS STEPS BEST PROGRAMMED IN SPACE	PROCESS STEPS TO BE RESOLVED BY EXPERIMENT/TEST	ALTERNATIVES IN PROCESS STEPS TO BE RESOLVED BY EXPERIMENT/TEST	PROCESS STEPS PREFERRED TO BE PERFORMED IN SPACE
SEPARATION OF ISOENZYMES	SEPARATION	PREPARATION OF GELS, SAMPLES (INCLUDING LOADING OF SEPARATOR).	PROTEIN DETERMINATION VS. ACTIVITY DETERMINATION PACK ISOENZYMES VS. PRODUCE AND PACK ANTIBODIES	-----
TRANSPARENT OXIDE PROCESSING	POSITION CONTROL, HEATING (DEGASSING AND MELTING), COOLING, COLLECTION	LOAD LEVITATION SYSTEM	HIGH RATE VS. MODERATE RATE HEATING, MELT TEMP. VS. SUPER HEAT	-----
HIGH PURITY TUNGSTEN X-RAY TARGET PROCESSING	PROCESS CONDITIONS, LEVITATION (POSITION CONTROL), HEAT (OUTGASSING AND MELTING, COOLING	SHAPE THE TARGET	HIGH PURITY VS. COMMERCIAL TUNGSTEN, 0.91 VS. 096 KG TARGET	-----
FABRICATION OF SURFACE ACOUSTIC WAVE COMPONENTS	CRYSTAL GROWING, FABRICATE MASK, DEPOSIT PIEZO FILM	----	----	ULTRA-CLEANING METALLIZATION RESIST-COATING MASK ALIGNMENT X-RAY EXPOSURE

Figure 14. Summary of Selected Approaches

KNOWLEDGE GAPS	EXPERIMENTS AND VERIFICATION TESTS	EXPERIMENT AND TEST REQUIREMENTS (SUMMARY)
DEGASSING RATES EFFECTS OF TEMPERATURE, VACUUM, INITIAL TUNGSTEN PURITY.	DEGASSING TIMES VS TEMPERATURE, TYPE AND QUANTITY OF GASES, DEGASSING EFFECTS ON MECHANICAL PROPERTIES, INTERSTITIALS CONTENT.	STANDARD GROUND LAB, VACUUM INDUCTION FURNANCE, RF GENERATOR, MASS SPECTROMETER, GAS SAMPLING SYSTEM, PROCESS INSTRUMENTATION, MATERIALS AND GAS ANALYSIS EQUIPMENT, SPECTROSCOPE, 2-1/2 WEEKS PER SPECIMEN, MANUAL CONTROL.
POSITIONING, HEATING, DEGASSING, MELTING, SUPERCOOLING ADVANTAGES, SELECTION OF PROCESS ATMOSPHERE, ASSESSMENT OF PROCESSED TUNGSTEN METALLURGICAL AND OPERATIONAL PROPERTY GAINS.	LEVITATION, HEATING, MELTING TEST FOR R/F AND/OR ELECTRON BEAM AS CONTROL AND HEATER. ALSO EFFECTS OF VACUUM AND INERT GAS ON TUNGSTEN EVAPORATION. ALSO SUPERCOOLING EXPERIMENT.	STANDARD GROUND LAB, EQUIPMENT AS ABOVE PLUS INERT GAS SYSTEM AND COPPER OR CERAMIC COOLING CRUCIBLE. ALSO OPERATIONAL TESTING (TEST X-RAY TUBES, PROGRAMMED TEST APPARATUS, STANDARD SHIELDED TEST CHAMBER, ETC.). 4-1/2 TO 5 HOURS PER RUN PLUS 1 WEEK CHARACTERIZATION PLUS 15 DAYS OPERATIONAL TESTING. MANUAL PLUS AUTOMATED OPERATIONAL TESTING.
ASSESSMENT OF POSITIONING SYSTEM AND ACQUISITION OF DESIGN DATA.	ZERO "G" VERIFICATION TEST OF POSITIONING SYSTEM.	DROP TOWER, KC135, OR SOUNDING ROCKET. TEST PACKAGE OF POSITIONING DEVICE, TUNGSTEN SPECIMEN, CAGING SYSTEM, POSITION MONITORING INSTRUMENTATION, RECORDER, POWER SUPPLY AND DISTRIBUTION, PHOTOGRAPHIC APPARATUS, MEASUREMENT GRID. AUTOMATED. MINIMUM TEST TIME 4 TO 10 SEC - DROP TOWER, 20 TO 40 SEC - KC135, 4 TO 10 MIN - SOUND ROCKET. TELEMETRY OR RECORDING OF DATA, RECOVERY OF TEST PACKAGE AND RECORDER DATA.
FINAL PROCESS DESIGN DATA DEFINITIONS.	ZERO "G" PROCESS VERIFICATION TEST.	SHUTTLE FACILITY. TEST PACKAGE AS ABOVE, AUGMENTED FOR MULTIPLE SAMPLES, EXTENDED TEST TIMES, AND COMPLETE PROCESS INSTRUMENTATION. PROVISION FOR CREW OBSERVATION, MONITORING AND PROCESS MODIFICATION. AUTOMATED PROCESS, MANUAL RECYCLE. 1-1/2 - 3 HOURS PER RUN, PLUS 15 DAYS OPERATIONAL TESTING, TELEMETRY OF DATA, RECOVERY OF TEST PACKAGE AND PROCESSED SAMPLES.

Figure 15. Typical Requirements for Experiments to Verify Selected Approach for High Purity Tungsten X-ray Targets

V.2 DEFINITION OF REQUIREMENTS FOR EXPERIMENTS AND TESTS

Where selections of specific process steps could not justifiably be made, or where the critical elements of each selected approach were considered inadequately supported by available state-of-the-art, the User/Study Team effort identified the "gaps" in available knowledge.

Such gaps then represent the scientific or technology "questions" that require "answers" before the subject process can be utilized. Those answers can only be provided through the performance of experiments and tests.

The User/Study Team once again collaborated in synthesizing space "know how" with the expertise in the four product areas to identify the required discipline and technology experiments and tests as well as the requirements which define them. As a brief example of the results of that fusion, Figure 15 provides a partial extract of knowledge gaps, required experiments and experiment requirements identified for processing Tungsten X-ray Targets.

As part of the effort in defining experiment and test requirements, it was generally agreed that, in addition to satisfying technical needs, a program of tests aimed at developing commercial products would need to satisfy two further criteria: A test program must be economical, and it must not be so space-dependent that little could be accomplished in the 6 years prior to Space Shuttle availability.

The "low cost testing" concept was thus adopted. With the aid of personnel from NASA-MSFC, Wallops Station, GSFC, Lewis, General Electric's Space Sciences Lab and from Aerojet General, we assembled a set of capabilities, limitations, and conditions for a number of relatively low cost, available test "facilities" which might provide for some analogous or simulated experiment or test requirements established previously. Since many potentially useful facilities available to the Aerospace industry are not commonly of interest to commercial industry, this information stimulated the interest and consideration of the Users. As a result, a number of experiments and tests were identified for "low cost testing".

Figure 16 provides a summary of all the experiments and tests identified for the four Ideas of this Study.

V.3 MISSION PROFILES FOR EXPERIMENTS AND TESTS

To assure compatibility between the derived experiment and test requirements, and the various identified facilities, brief mission profiles were constructed for key test series. Major functions to be carried out prior to, during, and after, testing were tabulated, as were timing and types of data. Figure 17 is a summary of the mission profile data constructed during the Study.

IDEA / FACILITY	SEPARATION OF ISOENZYMES	TRANSPARENT OXIDE PROCESSING	HIGH PURITY TUNGSTEN X-RAY TARGETS	FABRICATION OF SURFACE ACOUSTIC WAVE COMPONENTS	TOTAL
GROUND LAB	8	6	4	4	22
CENTRIFUGE	2	--	--	--	2
ENGINEERING TEST LAB	2	1	1	1	5
DROP TOWER	--	1	1	1	3
KC–135	3	1	1	3	8
SOUNDING ROCKET	--	2	3	2	7
SPACECRAFT	7	--	--	1	8
SHUTTLE SORTIE LAB	4	3	2	2	11
TOTAL	26	14	12	14	66

EACH NUMERICAL ENTRY REPRESENTS A SERIES OF TESTS RANGING FROM 1 TO 120 RUNS

Figure 16. Summary of Experiments or Tests Needed

IDEA / FACILITY	SEPARATION OF ISOENZYMES	TRANSPARENT OXIDE PROCESSING	HIGH PURITY TUNGSTEN X-RAY TARGETS	FABRICATION OF SURFACE ACOUSTIC WAVE COMPONENTS
GROUND LAB	1 DAY TO 2 MONTHS SEPARATION, BIOASSAY	7 HOURS TO 2 DAYS ANALYSIS, HEATING, MELT, COOL, MATERIAL CHARACTERIZATION	3.5 HOURS TO 2.5 WEEKS SPECIMEN PREP., HEAT, MELT, COOL, MATERIAL CHARACTERIZATION	1 MIN. TO 2 DAYS CRYSTAL GROWTH, VIBRATION MEASUREMENT, X-RAY CRYSTALLOGRAPHY
CENTRIFUGE	10 MINUTES TRAJECTORY ACCELERATION	———	———	———
ENGINEERING TEST LAB	3 TO 4 DAYS/SPECIMEN PREP., BIO-ASSAY, SEPARATION, ANALYSIS	0.5 HOUR TO 5 DAYS SETUP, OPERATE EQUIP., RECORD DATA	4.5 TO 5 HOURS PLUS 15 DAYS OP. TESTING (GRD) HEAT, MELT, COOL, SUPER-COOL, MATERIAL CHARACT.	1 TO 2 DAYS SETUP, OPERATE PROCESS, EQUIP., RECORD DATA, INSPECT.
DROP TOWER	———	*3 TO 10 SEC./INITIATE* TEST, AUTOMATED POSITIONING, TELEMETER DATA	*3 TO 10 SEC./POSITIONING,* RECORD DISPLACEMENT DATA, RECOVER	*4 TO 10 SEC./* INSTALL "SPINNER" TEST PACKAGE, INITIATE TEST, OPERATE "SPINNER" RECORD DATA
KC-135	20 TO 40 SEC. / PREPARE TEST PKG. POSITION, RECORD DATA	20 TO 40 SEC. / INITIATE TEST, AUTOMATED POSITIONING, RECORD DATA.	20 TO 40 SEC. / POSITIONING, RECORD DISPLACEMENT DATA.	20 TO 40 SEC. / OPERATE ULTRACLEANING AND METALLIZATION TEST PACKAGES. RECORD DATA
SOUNDING ROCKET	———	6 TO 10 MINUTES/INITIATE TEST, AUTOMATED POSITIONING, TELEMETER DATA.	4 TO 10 MINUTES/POSITIONING, DEGASSING, TELEMETER DATA, RECOVER	1 TO 10 MINUTES/OPERATE ULTRACLEANING AND METALLIZATION TEST PACKAGES. RECORD DATA
SPACECRAFT	*1 TO 2 DAYS/PRE-*LAUNCH OPS., OPERATE EQUIP., TELEMETRY DATA	———	———	1 DAY/MEASURE VIBRATIONS, WITH AND WITHOUT ISOLATORS, TELEMETRY DATA
SHUTTLE SORTIE LAB	1 TO 2 DAYS/CHECK-OUT, OPERATE PROCESSING EQUIPMENT	0.5 HOUR TO 5 DAYS CHECKOUT, OPERATE PROTOTYPE PROCESSING EQUIPMENT	1.5 TO 3 HOURS/PLUS 15 DAYS OPERATIONAL (GRD) TESTING. OPERATE PROTOTYPE EQUIPMENT MATERIAL CHARACT.	2 DAYS / CRYSTAL GROWTH, PACKAGING, OPERATE PROTOTYPE EQUIPMENT

Figure 17. Summary of Mission Profiles (Range of Run Durations/Key Functions

V.4 DEVELOPMENT PROGRAM TIMELINES AND MILESTONES

The proceeding effort essentially completed the technical requirements portion of the Study. Those requirements were then utilized as the basis for establishing the technical planning data - *the development timelines and milestones.*

The User/Study Team applied the previously developed work-*ing relationships* to this problem by having the Space Division members establish the broad outlines of the space and space-related program elements, the Users establish the ground laboratory, engineering, and organizational elements, and then fitting them together in timing, work flow, and detailed milestones through the usual dialog method. The only constraint placed on this process was the guideline concerning the 1982 Shuttle Flight as the earliest full-scale production flight. Thus, several Users have called for automated spacecraft flights. The majority of tests dependent on such a facility can very likely be satisfied with a "piggy-back" position on either an orbiting booster or a spacecraft, provided sufficient weight is allowed for power and communications. Alternatively, such test could be delayed until the Shuttle could accommodate them on an early flight, perhaps with the Long Duration Exposure Facility

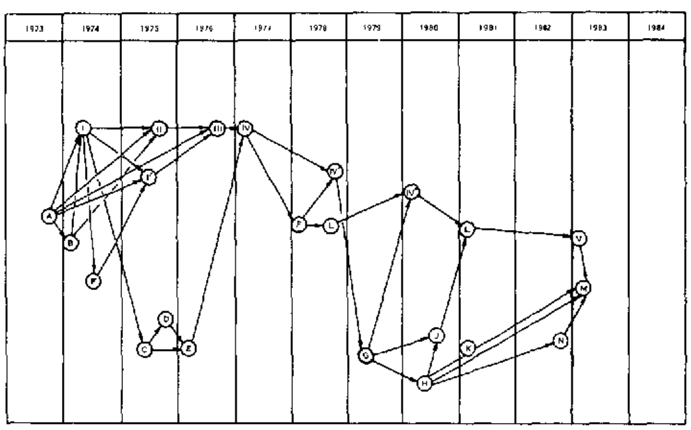
(L.D.E.F.). Figure 18 summarizes the content of the development schedules established in this Study. The detailed schedules appear in Volume II of this report.

- ANALYSES STARTING IN 1973
- LABORATORY TESTING LATE 1973, HEAVY IN 1974 - 1976, SOME TO 1979
- DROP TOWER TESTS 1974, MAINLY 1975
- KC-135 TESTS 1975, MAINLY 1976, SOME IN 1977 - 1978
- SOUNDING ROCKET TESTS, SOME IN 1975 - 1976, HEAVY IN 1977, SOME IN 1978 - 1979
- PRESHUTTLE SPACECRAFT TESTS, 1975, 1977, HEAVY IN 1978, 1979
- SPACE SHUTTLE TESTS, HEAVY IN 1979 - 1980, SOME THROUGH 1983
- SUPPORT EQUIPMENT AVAILABILITY, MID-1978 TO MID-1983
- PROTOTYPE/ PILOT PLANT DEMONSTRATIONS, MID-1981 TO MID-1982
- GROUND FACILITY PREPARATION, SOME 1975 TO 1977, 1979 TO 1982
- FULL-SCALE OPERATIONS BEGIN, 1982 TO MID-1983
- ADMINISTRATIVE AND TECHNICAL ORGANIZATION SET UP, 1973 - 1974, LATER MODIFICATION
- FINANCIAL ARRANGEMENTS DEFINED: INITIALLY, LATE 1973, EARLY 1974; FINAL 1975, 1978 - 1980

Figure 18. Summary of Development Program Highlights

V.5 DECISION FLOWS

The final effort of the Phase II Study was to derive from the technical plan the flow of decisions that would be required to implement that plan. The Study Team, working with the Users, evaluated each timeline and milestone as to what would have to precede, and what would have to follow, what the necessary conditions would be for proceeding to the next timeline and/or milestone. In each case where a required decision was noted, the alternatives being faced were documented, and each User was requested to indicate, from his business point of view, his estimate of the probabilities associated with each alternative. From the same viewpoint, he was asked to indicate his preferred alternative. Construction of the decision flows very quickly indicated, in several cases, where there were nodes in the decision process. These should require specific attention, if the programs are implemented, since such points are of high criticality to the continuity of a program. Figure 19 is one example of the decision flows constructed during this Study. It can be seen that implementation of the Separation of Isoenzymes in space will require careful handling of Test Series IV, a major node.



KEY	DECISION TO BE MADE	ALTERNATES	PROBABILITY	BEST ALTERNATIVE
A.	FUNDING FOR EXP. SERIES I-III	A. IN-HOUSE FUNDING	10	
		B. NASA FUNDING	90	•
B.	ASSIGNMENT OF PERSONNEL	A. REASSIGN AVAIL. PERSONNEL	30	
		B. HIRE NEW PERSONNEL	70	•
C.	FUNDING FOR EXP. SERIES IV	A. NO FUNDING	10	
		B. IN-HOUSE FUNDING	10	
		C. NASA FUNDING	80	•
D.	NEW LAB SPACE	A. ADAPT EXISTING	20	
		B. BUILD NEW, SEPARATE	10	
		C. ADDITION TO PRESENT	70	
E.	HIRING OF PERSONNEL	A. HIRE NEW PERSONNEL	30	
		B. SUBCONTRACT	70	•

KEY	DECISION TO BE MADE	ALTERNATES	PROBABILITY	BEST ALTERNATIVE
F.	RESERVE FLIGHT OPPORTUNITY ON AUTOMATED SPACECRAFT	A. RESERVE	80	•
		B. CANNOT RESERVE	20	
G.	PATENT RIGHTS FOR EQUIPMENT OF EXP. SERIES IV	A. POLYSC. OWN OUTRIGHT	30	•
		B. NASA OWNS	30	
		C. POLYSC. LICENSE	40	
H.	DEFINE OWNERSHIP FINANCES OF COMMERCIAL SPACE PRODUCTION	A. POLYSC. OWNS	10	•
		B. NASA OWNS	50	
		C. LICENSE TO CONTRACTORS	40	
J.	FUNDING FOR DESIGN, FABRIC. AND TESTING OF EXP. SERIES V	A. IN-HOUSE FUNDING	10	
		B. NASA FUNDING	90	•
K.	MAKE/BUY FOR INITIAL BIOLOGICALS	A. POLYSC. PRODUCE	10	
		B. POLYSC. SUBCONTRACTS FOR PRODUCTION	80	•
		C. POLYSC. BUY FROM ESTAB. SOURCE	10	
L.	RESERVE PL ACCOMMODATION ON SHUTTLE	A. RESERVE	80	•
		B. CANNOT RESERVE	20	
M.	INITIATE COMMERCIAL SPACE PRODUCTION	A. IN-HOUSE	50	•
		B. SUBCONTRACT FOR PROCESSING	50	
I.	VALUE OF PHENOMENOLOGY RESULTS FROM TEST SERIES I	A. ALL SUPPORT SPACE PROCESSING	20	
		B. SUFFICIENT SUPPORT	70	•
		C. INSUFFICIENT SUPPORT OF SPACE PROCESSING	10	
II.	EVALUATION OF SEPARATION CONCEPTS IN TEST SERIES II	A. LIKELY CANDIDATE INDICATED	80	•
		B. NOT INDICATED	20	
III.	EFFECTS OF NON-SPACE ENVIRONMENT IN TEST SERIES III	A. EFFECTS DETRIMENTAL	10	
		B. NOT DETRIMENTAL	90	•
IV.	EVALUATION OF PERFORMANCE OF PROCESSING EQUIPMENT IN TEST SERIES IV	A. ACCEPTABLE	70	•
		B. UNACCEPTABLE	30	
V.	PROOF OF PROCESS QUALITY, TIMING	A. SUFFICIENT FOR COMMERCIAL PROCESS	80	•
		B. INSUFFICIENT	20	
I'	VERIFICATION OF PHENOMENOLOGY IN SPACECRAFT TEST	A. VERIFIED	80	•
		B. NOT VERIFIED	20	
IV'	VERIFICATION OF SELECTED PROCESS EQUIPMENT DESIGN DATA IN ZERO 'G' AIRCRAFT AND SHUTTLE FLIGHT	A. VERIFIED	80	•
		B. NOT VERIFIED	20	
IV''	VERIFICATION OF PROCESS EQUIPMENT PERFORMANCE IN SHUTTLE FLIGHT	A. VERIFIED	90	•
		B. NOT VERIFIED	10	

Figure 19. Decision Flow for Separation of Isoenzymes

VI STUDY LIMITATIONS

This Phase II Study has been performed within the administrative and technical bounds defined by the contract for the Study, the direction of the C.O.R., and the growing, but limited, state-of-the-art in space processing. The final results of the Study, documented in the Final Report, are valid only within the limitations noted.

VI.1 LIMITATIONS OF A TECHNICAL NATURE

Feasibility of Space Processes. In this Phase of the Study, as in Phase I, only limited funding was available for in-depth analysis of the disciplines involved in the Space Processing of the four products under study. The kinetics, thermodynamics, mechanics, etc. underlying many of the potential process steps have, therefore, been addressed only in a few cases. The Appendices in Volume II, Book 2 are representative of that effort. For the most part, engineering and scientific judgement, based on the space "know-how" of the Space Division Study Team, and on the product "know-how" of the Users have been used to extrapolate, or to draw analogous conclusions, from such available information as Apollo Electrophoresis Experiments, Skylab Metal Melting Tests, Sounding Rocket Levitation Melting Experiments, etc.

Such methods limit the degree of certainty with which the specific processes and process steps identified in this Study can be supported at this time. The Study Results must, therefore, be considered conceptual for the time being.

Selection of Process Approach. An analogous limitation, due to present state-of-the-art, is the inability to select a single, unequivocal process for each product in the Study. Within each of the Process Approaches selected in Task 1 there are presently sufficient unknowns to warrant retaining one or more options, which would be resolved by experiments or tests. Thus the experiment and test requirements reflect the need for data to select from among alternatives, as well as the development of processes.

VI.2 LIMITATIONS OF AN ADMINISTRATIVE NATURE

User Concerns. As in Phase I, there is still some concern among the Users as to the legal/financial aspects of NASA/User involvement in commercial products. While such concern did not appear to inhibit this Study, the early timing of milestones and decisions related to this concern are prominent in the technical and administrative data issuing from this Study on all the four products.

VII IMPLICATIONS FOR RESEARCH

Each of the four Ideas under study has, in the process of defining implementation approaches, extracting knowledge "gaps", identifying experiments, and deriving experiment requirements, uncovered problems implying the need for research. Section V of this Volume summarizes those needs.

Some of those needs, based on the facilities identified for specific experiments and tests, may require expenditure of moderate amounts of resources. Other needs, based on the timelines constructed during the Study, require no early action.

The most reasonable approach to research in the areas under study here, is to go forward with those low cost, near term requirements noted in the timelines. For example, typical efforts should be initiated on the following:

1. Vacuum degassing, levitation control, heating of Tungsten - in Ground Laboratory
2. Tests of Electron Beam Resolution and Mask Fabrication for Surface Acoustic Wave Components - in Ground Laboratory
3. Measurement of Low Frequency Vibration Spectra - in Spacecraft
4. Mobility, convection, pathlength effects on Large Pore Gel Electrophoresis - in Ground Laboratory
5. Trace impurities analysis, x-ray crystallography of Candidate Oxides - in Ground Laboratory.

VIII SUGGESTED ADDITIONAL EFFORT

Interest in Space Processing continues among the four User organizations involved in the Phase II Study. The initial interest displayed by the eight other Users whose Ideas were identified as worth continuing effort in Phase I, has been allowed to lag, and nothing has been done to maintain the interests of the other 60 to 70 potential Users who were involved in Phase I. It is suggested that it would be beneficial to the Space Processing program to maintain the interest of all the above parties and to gain the interest of additional non-aerospace industry. Briefly, the following efforts are suggested:

1. A Business Planning Study. Continue the relationship with up to four of the Users who participated in Phases I and II by developing business plans for Space Processing of their products. Aim the effort toward the realities of the commercial world, equipment requirements, and resource requirements by specifying the tasks listed in Figure 20.

PURPOSE:	TO ASSESS THE VALIDITY OF AVAILABLE STANDARD BUSINESS PLANNING AND MARKET FORECASTING METHODS FOR DETERMINING THE COST AND RESOURCE REQUIREMENTS OF SPACE PROCESSING SPECIFIC COMMERCIAL PRODUCTS.
TASKS:	1. PREPARE BUSINESS PLANS AND MARKET FORECASTS FOR HIGH PURITY TUNGSTEN X-RAY TARGETS AND FOR TRANSPARENT OXIDES.
	2. IDENTIFY PAYLOAD EQUIPMENT GROUPINGS, SHUTTLE SORTIE FLIGHTS, SHUTTLE/SPACE LAB RESOURCES, AND SPACE PROGRAM COSTS, TO ACCOMPLISH THE R&D PHASES OF THE BUSINESS PLANS.
	3. ESTIMATE FLIGHT SYSTEM RESOURCES, SPACE OPERATIONS COST, AND UNIT PRODUCT COSTS. DETERMINE SENSITIVITIES OF COSTS TO KEY ASSUMPTIONS. RECOMMEND COST DATA ACQUISITION METHODS, AND COST OPTIMIZATION APPROACHES.

Figure 20. Business Planning Study

2. Promotion of Space Processing. Initiate a low key effort for the no-cost exchange of information between NASA (Skylab results, MSFC results, Contract results, etc.) and potential Users identified in B.U.S. Phase I (Ground Lab results, New Products, New Needs, Problem Areas, etc.), simple newsletters or even standard NASA releases and/or reports should accomplish the objectives sought here.

3. Identification of Additional Beneficial Uses of Space. Initiate an extension of the B.U.S. Phase I effort to uncover additional products and Users. We have contacted much less than 1 percent of U.S. commercial industry, and after a lapse of almost a year since the completion of Phase I, receive occasional calls from new sources. This is indicative of a vast, untapped source of additional Ideas for Space Processing.

4. Initiation of Experiment Programs. As mentioned in Section VII - Implications for Research, a number of low cost, near term experiments have been identified for the products in this Study. Active involvement of NASA in initiating such experiments by the identified Users would increase the credibility of commercial Space Processing. A brief review of present administrative practices for initiating such programs indicates a possible need for modifying the methods for reaching potential Users and for simplifying implementation procedures.